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Invention: GROUP III NITRIDE COMPOUND SEMICONDUCTOR LIGHT-EMITTING DEVICE

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- ☐ Provisional Application
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- ☐ Design Application
- ☐ Reissue Application
- ☐ Plant Application
- ☐ Substitute Specification
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SPECIFICATION

GROUP III NITRIDE COMPOUND SEMICONDUCTOR LIGHT-EMITTING DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a group III nitride compound semiconductor light-emitting device of high light intensity.

The present application is based on Japanese Patent Application No. Hei. 11-90719, which is incorporated herein by reference.

2. Description of the Related Art

Sub A1

~~Fig. 2 is a typical sectional view showing a structure of a group III nitride compound semiconductor light-emitting device 200 according to the conventional art.~~

Sub A2

~~The group III nitride compound semiconductor light-emitting device 200 is considered as a representative of conventional-art light-emitting devices of the type having layers of group III nitride semiconductors laminated on a substrate.~~

The group III nitride compound semiconductor light-emitting device 200 comprises a sapphire substrate 11 as a substrate, a buffer layer 12 of aluminum nitride (AlN) laminated on the sapphire substrate 11, an n^+ layer 13 of a high carrier density formed of GaN doped with silicon (Si) and laminated on the buffer layer 12, an intermediate layer 14 laminated on the n+ layer 13, an n-type clad layer 15 of GaN laminated on the intermediate layer 14, a light-emitting layer 16 of a multilayer quantum well structure (MQW) laminated on the n-type clad layer

15 and composed of alternately laminated well layers 161 of GaInN and barrier layers 162 of GaN, a p-type clad layer 18 of p-type AlGaN laminated on the p-type clad layer, and a p-type contact layer 19 of p-type GaN laminated on the p-type clad layer.

Sub A3

In the aforementioned light-emitting device 200, the barrier layers 162 are made substantially uniform in thickness so as to be generally in a range of 70 to 80Å. Moreover, from the point of view of improvement in color purity, the intermediate layer 14 of InGaN is provided, and the n-type clad layer 15 having the same thickness and composition as each of the carrier layers 162 is also formed.

Sub A4

In the background-art group III nitride compound semiconductor light-emitting device such as the aforementioned light-emitting device 200, or the like, there is a problem in that the effect of confining carriers in the light-emitting layer 16 against the high carrier density n^+ layer 13 is unable to be obtained sufficiently because the thickness of the n-type clad layer 15 under the light-emitting layer 16 is substantially equal to the thickness of each of the barrier layers 162, and therefore light-emitting efficiency is low in spite of very good color purity.

SUMMARY OF THE INVENTION

The present invention is designed to solve the aforementioned problem and an object thereof is to provide a light-emitting device of high light intensity by securing the effect of confining carriers in the light-emitting layer

against the high carrier density n^+ layer sufficiently while keeping color purity intact.

Another object of the present invention is to provide a light-emitting device of higher light intensity by the synergistic effect of an n-type clad layer and an intermediate layer according to the present invention to bring the aforementioned carrier confinement effect.

To solve the aforementioned problem, the following means are effective.

That is, a first means, which is applied to a group III nitride compound semiconductor light-emitting device comprising a light-emitting layer of a multilayer quantum well structure composed of alternately laminated well layers and barrier layers, is in that the device further comprises an n-type clad layer which is provided to be in contact with the light-emitting layer and which is made thicker than each of the barrier layers.

A second means, which is applied to the first means, is in that the thickness of the n-type clad layer is set to be not smaller than 100Å.

A third means, which is applied to the first means, is in that the thickness of the n-type clad layer is set to be not larger than 500Å.

A fourth means, which is applied to any one of the first, second and third means, is in that the device further comprises an intermediate layer which is provided so as to be in contact with a face of the n-type clad layer opposite to the light-emitting layer.

A fifth means, which is applied to any one of the first, second, third and fourth means, is in that the intermediate layer is formed of $In_xGa_{1-x}N$ $(0<x<1)$.

A sixth means, which is applied to any one of the first, second, third and fourth means, is in that the intermediate layer is formed of $In_xGa_{1-x}N$ $(0.01 \leqq x \leqq 0.05)$.

The aforementioned problem can be solved by the above means.

Sub A57

According to the means of the present invention, carriers contributing to light emission can hardly ~~run~~ escape away from the light-emitting layer 16 toward the high carrier density n^+ layer 13 because the n-type clad layer 15 thicker than each of the carrier layers is formed to be in contact with the light-emitting layer 16 of the multilayer quantum well structure. That is, the carrier confinement effect can be obtained sufficiently by the n-type clad layer 15, so that light-emitting efficiency is improved.

Further, the thickness of the n-type clad layer 15 is preferably not smaller than 100 Å, more preferably in a range of from 150 to 500 Å. If the thickness is smaller than 100 Å, it is difficult to confine carriers in the light-emitting layer securely because the thickness is too small. If the thickness is contrariwise larger than 500 Å, the color purity is worsened. Also from the point of view of productivity, the thickness of the n-type clad layer 15 is preferably not larger than 500 Å.

When an intermediate layer is further provided just under the n-type clad layer, a light-emitting device of higher light

intensity can be achieved. GaInN is preferably used as a semiconductor for forming the intermediate layer.

Further, the light emission intensity of the light-emitting device has a strong correlation with the composition ratio x of indium (In) in the intermediate layer of $In_xGa_{1-x}N$. The light emission intensity of the light-emitting device 100 has an acute peak when the composition ratio x of indium (In) is about 0.03. Hence, the light-emitting device 100 exhibits high light intensity when x is in a range of "$0.01 \leqq x \leqq 0.05$".

If the composition ratio x of indium is smaller than 0.01, the light emission intensity is lowered. If the composition ratio x of indium is contrariwise larger than 0.05, the crystallinity of the intermediate layer deteriorates because the amount of indium is too large. As a result, semiconductor layers laminated after the intermediate layer cannot be formed with good quality, so that light emission intensity is lowered.

Incidentally, the group III nitride compound semiconductor according to the present invention is represented by the general formula $Al_xGa_yIn_{1-x-y}N$ ($0 \leqq x \leqq 1$, $0 \leqq y \leqq 1$, $0 \leqq x+y \leqq 1$), which may further contain group III elements such as boron (B) and thallium (Tl) and in which the nitrogen (N) may be replaced by phosphorus (P), arsenic (As), antimony (Sb) or bismuth (Bi). Accordingly, each of the layers such as the buffer layer, the barrier layers, the well layers, the clad layers, the contact layer, the intermediate layer, the cap layer, etc. in the group III nitride compound semiconductor light-emitting device may be formed of quaternary, ternary or binary $Al_xGa_yIn_{1-x-y}N$ ($0 \leqq x \leqq 1$, $0 \leqq y \leqq 1$, $0 \leqq x+y \leqq 1$) of an optional crystal

mixture ratio such as AlGaN, InGaN, or the like.

Features and advantages of the invention will be evident from the following detailed description of the preferred embodiments described in conjunction with the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

Fig. 1 shows a typical sectional view showing the structure of a group III nitride compound semiconductor light-emitting device 100 according to a specific embodiment of the present invention; and

~~Fig. 2 shows a typical sectional view showing the structure of a group III nitride compound semiconductor light-emitting device 200 according to the conventional art.~~

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will be described below on the basis of a specific embodiment thereof.

Fig. 1 is a typical sectional configuration view of a light-emitting device 100 constituted by group III nitride compound semiconductors formed on a sapphire substrate 11. A buffer layer 12 of aluminum nitride (AlN) about 25 nm thick is provided on the substrate 11. An n^+ layer 13 of a high carrier density, which is formed of GaN doped with silicon (Si) and which is about 4.0 μm thick, is formed on the buffer layer 12. An intermediate layer 14 of non-doped $In_xGa_{1-x}N$ ($0<x<1$) about 3000 Å thick is formed on the high carrier density n^+ layer 13.

Then, an n-type clad layer 15 of GaN about 250Å thick is laminated on the intermediate layer 14. A light-emitting layer 16 of a multilayer quantum well structure (MQW), which is constituted by an alternate laminate of well layers 161 of $Ga_{0.8}In_{0.2}N$ about 30Å thick each and barrier layers 162 of GaN about 70Å thick each, is formed on the n-type clad layer 15. The number of the well layers 161 is three. The number of the barrier layers 162 is two. A cap layer 17 of GaN about 70 Å thick is formed on the light-emitting layer 16. A p-type clad layer 18 of p-type $Al_{0.12}Ga_{0.88}N$ about 300Å thick is formed on the cap layer. A p-type contact layer 19 of p-type GaN about 100 nm thick is further formed on the p-type clad layer 18.

Further, a light-transparency positive electrode 20A is formed on the p-type contact layer 19 by metal evaporation whereas a negative electrode 20B is formed on the n+ layer 13. The light-transparency positive electrode 20A consists of a cobalt (Co) film about 15Å thick to be joined to the p-type contact layer 19, and a gold (Au) film about 60Å thick to be joined to the Co film. The negative electrode 20B consists of a vanadium (V) film about 200Å thick, and an aluminum (Al) or Al alloy film about 1.8 μm thick. An electrode pad 21 about 1.5 μm thick, which is made of a combination of either Co or Ni, Au and Al or made of an alloy thereof, is formed on a part of the positive electrode 20A.

A method for producing the light-emitting device 100 will be described below.

The light-emitting device 100 was formed by vapor growth in accordance with a metal organic vapor phase epitaxy method

(hereinafter abbreviated as "MOVPE"). The gasses used were ammonia (NH_3), carrier gas (H_2, N_2), trimethylgallium ($Ga(CH_3)_3$) (hereinafter referred to as "TMG"), trimethylaluminum ($Al(CH_3)_3$) (hereinafter referred to as "TMA"), trimethylindium ($In(CH_3)_3$) (hereinafter referred to as "TMI"), silane (SiH_4), and cyclopentadienylmagnesium ($Mg(C_5H_5)_2$) (hereinafter referred to as "CP_2Mg").

First, a single-crystal substrate 11 having a face a cleaned by an organic cleaning process as a main face was attached to a susceptor placed in a reaction chamber of an MOVPE system. Then, the substrate 11 was baked at a temperature of 1100°C while H_2 was introduced into the reaction chamber under normal atmospheric pressure.

Then, the temperature of the substrate 11 was decreased to 400°C and H_2, NH_3 and TMA were supplied so that a buffer layer 12 of AlN about 25 nm thick was formed on the substrate 11.

Then, while the temperature of the substrate 11 was kept at 1150°C, H_2, NH_3, TMG, and silane were supplied so that a high carrier density n^+ layer 13 of GaN having a film thickness of about 4.0 μm and an electron density of 2×10^{18} /cm^3 was formed.

Then, the temperature of the substrate 11 was decreased to 850°C and either N_2 or H_2, NH_3, TMG and TMI were supplied so that an intermediate layer 14 of $In_{0.03}Ga_{0.97}N$ about 3000Å thick was formed.

After the intermediate layer 14 was formed, the temperature of the substrate 11 was kept at 850°C and either N_2 or H_2, NH_3 and TMG was supplied so that an n-type clad layer 15 of GaN about 250Å thick was formed.

Then, either N_2 or H_2, NH_3, TMG and TMI were supplied so that a well layer 161 of $Ga_{0.8}In_{0.2}N$ about 30Å thick was formed. Then, a barrier layer 162 of GaN about 70Å thick was formed in the same condition as used for forming the n-type clad layer 15.

Two well layers 161 and one barrier layer 162 were further formed alternately in the same condition as described above to thereby form a light-emitting layer 16 of an MQW structure. A cap layer 17 thicker than 70Å was formed on the light-emitting layer 16 in the same condition as used for forming each of the barrier layers 162.

Then, the temperature of the substrate 11 was kept at 1150℃ and either N_2 or H_2, NH_3, TMG, TMA and CP_2Mg were supplied so that a p-type clad layer 18, which was made of p-type $Al_{0.12}Ga_{0.88}N$ doped with magnesium (Mg) and which was about 300 Å thick, was formed.

Then, the temperature of the substrate 11 was kept at 1100℃ and either N_2 or H_2, NH_3, TMG and CP_2Mg were supplied so that a p-type contact layer 19, which was made of p-type GaN doped with Mg and which was about 100 nm thick, was formed.

Then, an etching mask was formed on the p-type contact layer 19. After a predetermined region of the mask was removed, the non-masked portion of the p-type contact layer 19, the p-type clad layer 18, the light-emitting layer 16, the intermediate layer 14 and a part of the n^+ layer 13 were etched with a chlorine-containing gas by reactive etching to thereby expose a surface of the n^+ layer 13.

Then, a negative electrode 20B for the n^+ layer 13 and

a light-transparency positive electrode 20A for the p-type contact layer 19 were formed by the following procedure.

(1) After a photo resist was applied, a window was formed in a predetermined region in the exposed face of the n^+ layer 13 by photolithography. After evacuation to a high vacuum of the order of 10^{-4} Pa or less, a vanadium (V) film about 200 Å thick and an Al film about 1.8 μm thick were formed by evaporation. Then, the photo resist was removed. As a result, the negative electrode 20B was formed on the exposed face of the n^+ layer 13.

(2) Then, a photo resist was applied onto a surface evenly and then an electrode-forming portion of the photo resist on the p-type contact layer 19 was removed by photolithography so that a window portion was formed.

(3) After evacuation to a high vacuum of the order of 10^{-4} Pa or less, a Co film about 15Å thick was formed on the photo resist and the exposed portion of the p-type contact layer 19 and an Au film about 60Å thick was further formed on the Co film by an evaporation apparatus.

(4) Then, the sample was taken out from the evaporation apparatus and the Co and Au films deposited on the photo resist were removed by a lift-off method so that the light-transparency positive electrode 20A was formed on the p-type contact layer 19.

(5) Then, to form a bonding-purpose electrode pad 21 on a part of the light-transparency positive electrode 20A, a photo resist was applied evenly and a window was formed in the electrode pad 21-forming portion of the photo resist. Then,

a film about 1.5 μm thick, which was made of a combination of either Co or Ni, Au and Al or made of an alloy thereof, was formed by evaporation. A portion of the film, which was deposited on the photo resist and which was made of a combination of either Co or Ni, Au and Al or made of an alloy thereof, was removed by a lift-off method in the same manner as in the step (4) to thereby form an electrode pad 21.

(6) Then, the atmosphere for the sample was evaluated by a vacuum pump and an O_2 gas was supplied to thereby set a pressure of 3 Pa. In this condition, a process for alloying the p-type contact layer 19 with the positive electrode 20A and a process for alloying the n^+ layer 13 with the negative electrode 20B were performed at an atmospheric temperature of about 550°C by heating for about 3 minutes.

Thus, the light-emitting device 100 was formed.

With respect to a group III nitride compound semiconductor light-emitting device for emitting green light in a main wavelength range of from 510 nm to 530 nm, experiment has shown that relatively high light intensity is exhibited when the thickness of the p-type clad layer 18 is in a range of from 180Å to 500Å. More preferably, the thickness of the p-type clad layer 18 is in an optimum range of from 240Å to 360Å. When the thickness is in the optimum range, the highest light emission output can be obtained.

With respect to a group III nitride compound semiconductor light-emitting device for emitting blue light in a main wavelength range of from 460 nm to 475 nm, experiment has shown that relatively high light intensity is exhibited when

the thickness of the p-type clad layer 18 is in a range of from 90Å to 390Å. More preferably, the thickness of the p-type clad layer 18 is in an optimum range of from 120Å to 300Å. When the thickness is in the optimum range, the highest light emission output can be obtained.

The composition ratio x of aluminum (Al) in the p-type clad layer 18 made of p-type doped $Al_xGa_{1-x}N$ is preferably in a range of from 0.10 to 0.14. If x is smaller than 0.10, the light emission output is lowered because it is difficult to confine carriers in the light-emitting layer. If x is larger than 0.14, the light emission output is also lowered because stress applied to the light-emitting layer increases in accordance with the difference between lattice constants of crystals.

Although the above embodiment has shown the case where the light-emitting layer 16 in the light-emitting device 100 has a structure with two MQW cycles, the number of cycles in the light-emitting layer is not particularly limited. That is, the present invention can be applied to a group III nitride compound semiconductor light-emitting device with any number of cycles.

Further, each of layers such as the barrier layers, the well layers, the clad layers, the contact layer, etc. may be made of quaternary, ternary or binary $Al_xGa_yIn_{1-x-y}N$ ($0 \leqq x \leqq 1$, $0 \leqq y \leqq 1$) of an optional crystal mixture ratio.

Although the above embodiment further has shown the case where Mg is used as p-type impurities, the invention can be applied also to the case where a group II element such as

beryllium (Be), zinc (Zn), or the like, is used as the p-type impurities.

Further, the present invention can be applied to photodetectors as well as light-emitting devices.

This invention is not limited to the above description of the mode for carrying out the invention and embodiments thereof at all, and includes various modifications that can be conceived by those skilled in the art without departing from the scope of the claims.